# National Earthquake Hazards Reduction Program

## NIST/NEHRP Earthquake Engineering Research Update

**Advisory Committee on Earthquake Hazards Reduction**

April 9 & 10, 2015

# Presentation Outline

- NIST Program Overview
- Current and Planned Projects
  - Internal and External
  - Accomplishments
- Questions

# NIST/NEHRP Internal Projects

# Validation of ASCE 41 Procedures in Performance Based Seismic Engineering

Jay Harris, Matthew Speicher & Siamak Sattar

- To advance first-generation performance-based seismic engineering (PBSE) methods by assessing the performance of a set of code-compliant buildings using ASCE/SEI 41 methodologies.
  - Project 1: 3 Structural Steel Systems
  - Project 2: 1 Structural Steel System
  - Project 3: 1 Reinforced Concrete System


# Research Goals

- ASCE 7 and ASCE 41 were developed independently, with different goals. No systematic study has been performed to determine the correlation between ASCE 7 and ASCE 41.
- Develop a link between the performance implied in ASCE 7 to performance identified by ASCE 41 procedures
- Assessment of the applicability and accuracy of adopting first-generation performance-based seismic engineering (PBSE) analysis methods developed for evaluating existing buildings for use in performance-based design of new buildings

# Project Accomplishments

- A suite of steel buildings (4, 8 & 16 story) designed using ASCE/SEI 7 and assessed using ASCE/SEI 41
  - Special Moment Frames
  - Special Concentrically Braced Frames
  - Eccentrically Braced Frames
- Reports published in Feb. 2015


NIST Technical Note 1863-1

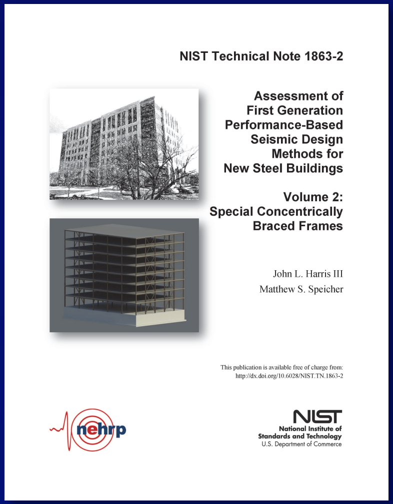
Assessment of First Generation Performance-Based Seismic Design Methods for New Steel Buildings

Volume 1: Special Moment Frames

John L. Harris III
Matthew S. Speicher

This publication is available free of charge from: http://dx.doi.org/10.6028/NIST.TN.1863-1

nehrp
NIST National Institute of Standards and Technology U.S. Department of Commerce


NIST Technical Note 1863-2

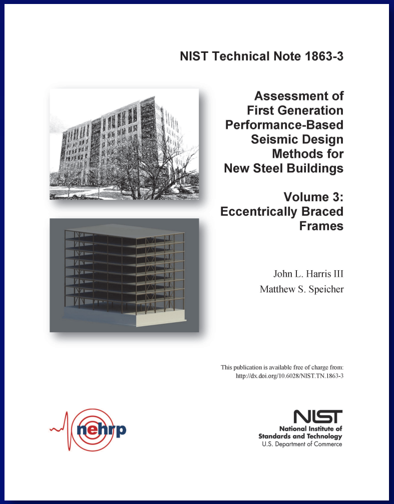
Assessment of First Generation Performance-Based Seismic Design Methods for New Steel Buildings

Volume 2: Special Concentrically Braced Frames

John L. Harris III
Matthew S. Speicher

This publication is available free of charge from: http://dx.doi.org/10.6028/NIST.TN.1863-2

nehrp
NIST National Institute of Standards and Technology U.S. Department of Commerce


NIST Technical Note 1863-3

Assessment of First Generation Performance-Based Seismic Design Methods for New Steel Buildings

Volume 3: Eccentrically Braced Frames

John L. Harris III
Matthew S. Speicher

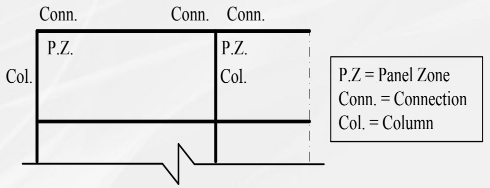
This publication is available free of charge from: http://dx.doi.org/10.6028/NIST.TN.1863-3

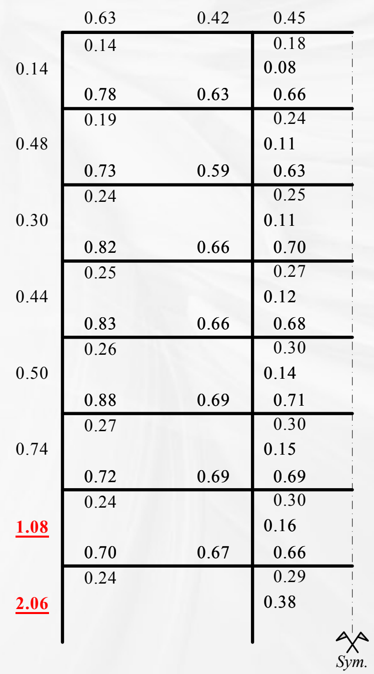
nehrp
NIST National Institute of Standards and Technology U.S. Department of Commerce

# Example Seismic Evaluation

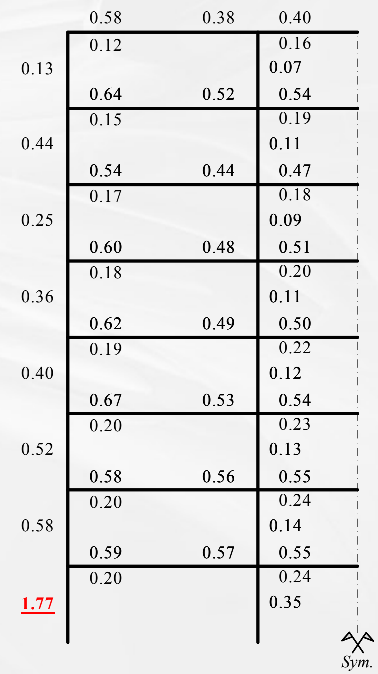
- LSP and LDP
  - Unity Check for Acceptance Criteria

$$\frac{Q_{UD}}{m\kappa Q_{CE}} \ or \ \frac{Q_{UF}}{\kappa Q_{CL}} \leq 1.0$$



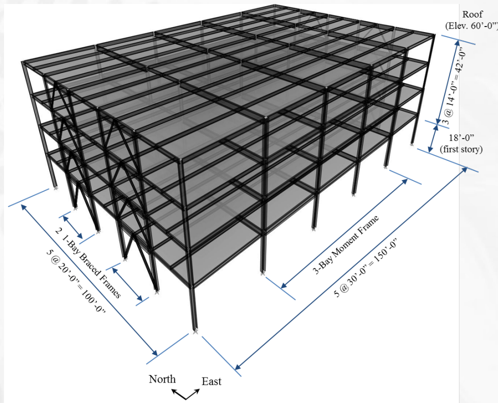

LSP



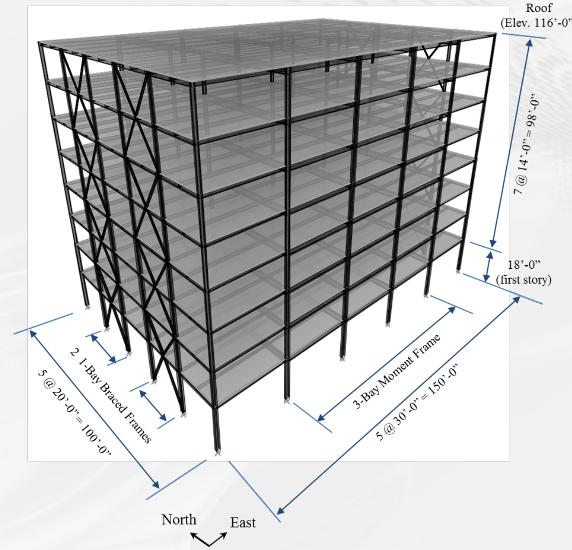

LDP

# Buckling Restrained Braced Frame - Ongoing

4-story

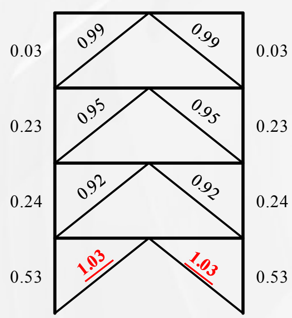


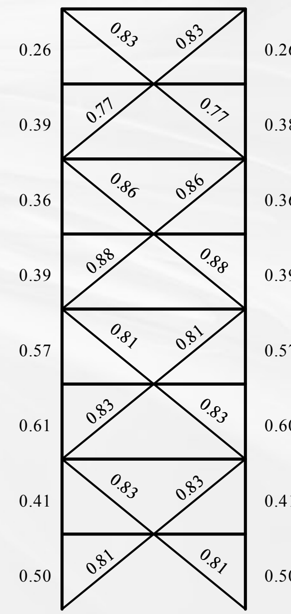

8-story




$DCR_N$ = Normalized demand-to-capacity ratio

CP under the BSE-2 using the LDP



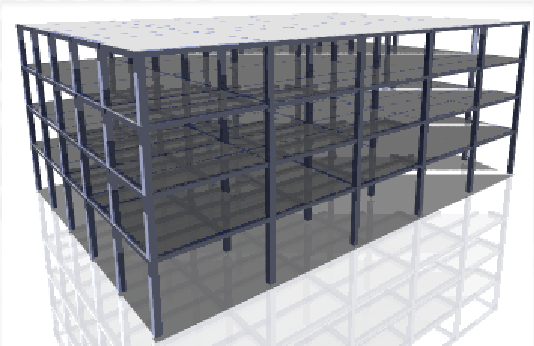

$DCR_N$

Results shown are preliminary

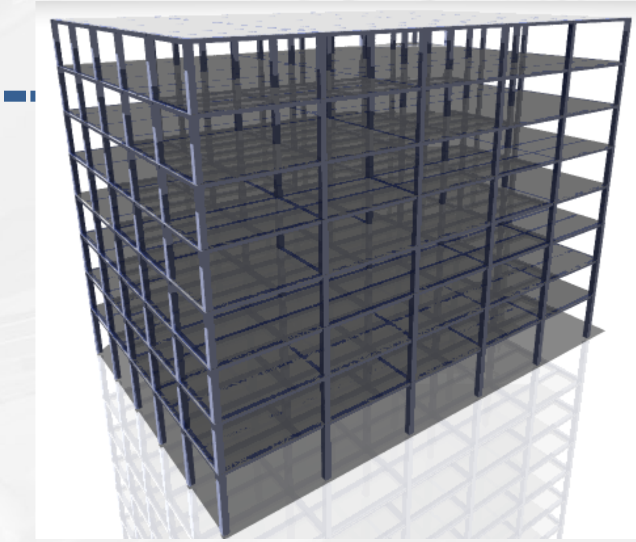
$DCR_N$

# Reinforced Concrete Special Moment Frames--Ongoing

4-story

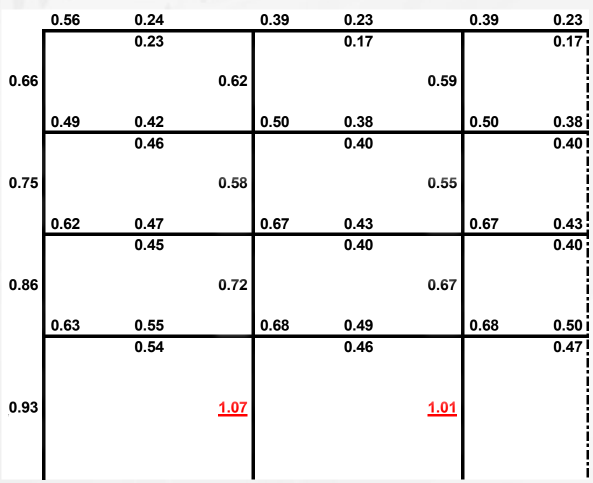


8-story

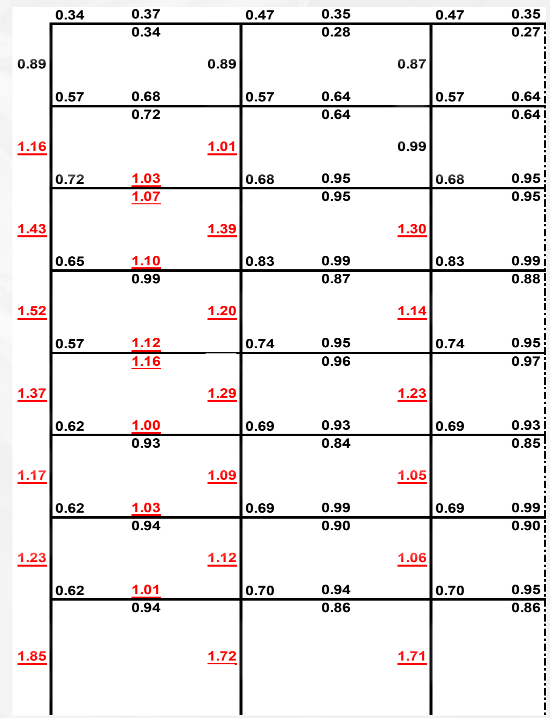


Linear Static Procedure (LSP); Collapse Prevention (CP)

$DCR_N$ = Normalized demand to capacity ratio




$DCR_N$




$DCR_N$

Results shown are preliminary

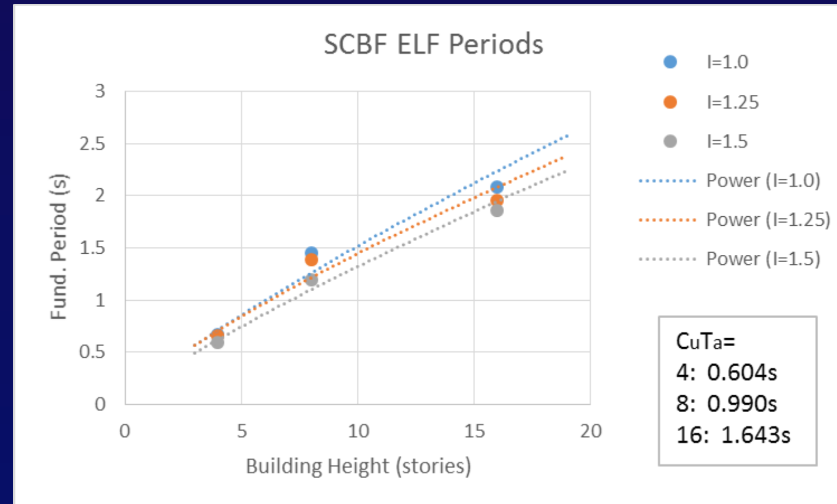
# Fundamental Period Approximation in ASCE 7

Matthew Speicher, Jay Harris
& Jeff Michel

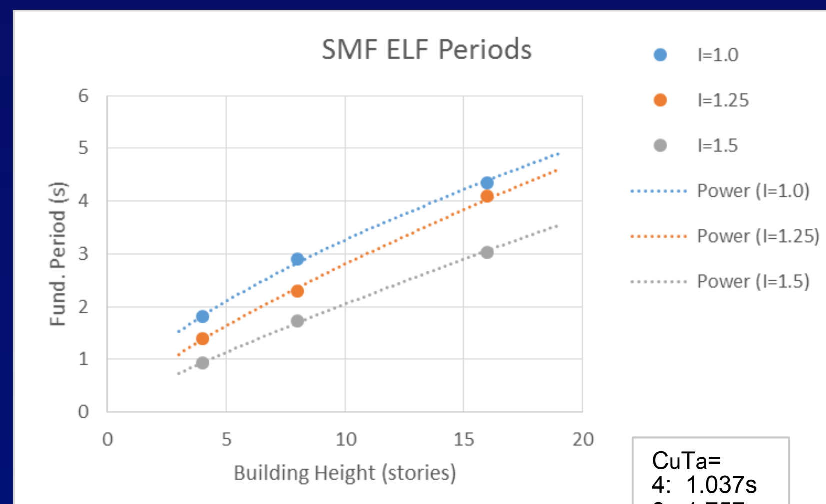
- **Project Objective**
  - Develop an approximate period relationship for use in structural modeling that accounts for limited redundancy and/or risk categories.
  - Evaluate alternatives using the ASCE 41 steel buildings
  - Propose new code expressions for use by practitioners

# Project Accomplishments

- 54 frames designed (3 heights × 2 design procedures × 3 systems × 3 importance factors)
- SMFs - stiffness (drift) controlled.
- SCBFs - strength controlled
- EBFs - mostly strength controlled
- Stiffness controlled systems more heavily affected by Risk Category








CuTa=
4: 1.037s
8: 1.757s
16: 3.017s

Results shown are preliminary

# Performance of Ordinary Reinforced Concrete Columns under Axial and Seismic Loading

Siamak Sattar & Steve McCabe

- Objective:
  - Developing a new analytical model for the determination of ordinary reinforced concrete column performance under significant levels of axial and cyclic lateral loading.
  - The goal is to provide a means to identify performance up to collapse for use in structural evaluation.
  - The models will assist designers in characterizing earthquake behavior of ordinary reinforced concrete columns, as required for advanced PBSE methodologies such as ASCE/SEI 41.

# Background Information/Motivation

- Why are ordinary columns important?
  - Susceptible to shear/axial failure
  - Widely used especially in low to moderate seismic zones.
  - Approximation to columns used in older nonductile buildings on the west coast
- Motivation:
  - Improve shear/axial failure modeling of ordinary columns
  - Important for PBSE evaluation/design of ordinary RC columns and assessment of existing columns.
- The Plan
  - Three year study conducted at Element Level and then the System Level
    - Assess/improve shear/axial load failure predictions
    - Coordinated with FEMA

# NEHRP Extramural Projects

- Completed by IDIQ Contractor – Applied Technology Council (ATC) – through Task Orders
  - TechBriefs
  - Roadmap Reports
  - Applied Research Projects
- Extramural Work Managed by NEHRP
- NIST/NEHRP Engineers Technically Engaged
- Two Experimental Projects at Outside Laboratories

# NEHRP Recent Extramural Projects

- TechBriefs –
  - Summary of recent research and best practices on important topics
  - 12 month duration, 40 pages in length
  - TO 35/TechBrief 9 *Special Reinforced Masonry Shear Walls*
    - *GCR 14-917-31, August 2014*
  - TO 36/TechBrief 10 *Wood Light-Frame Structural Diaphragms*
    - *GCR 14-917-32, September 2014*
  - TO 40/TechBrief 11 *Buckling Restrained Braced Frames (active)*

- Planned FY2016 Updates to TechBriefs 1-3 and ICSSC RP 8
- Planned FY2016 TechBrief on seismic design of precast concrete diaphragms (by request)

# NEHRP Extramural Research: Recently Completed Projects

- ATC 102/TO 28 *Research Plan for EQ Resilient Lifelines: NEHRP Research, Development and Implementation Roadmap*
  - *GCR 14-917-33; October 2014*
- New Extramural Project Underway – FY 2014:
  - ATC 126/TO 41 –*Community Resilience of Lifeline Systems*
    - *Direct extension of recently completed Task Order 28*
    - *Duration: 15 months*

# Stability of Steel Wide-flange Beam-Columns in Seismic Loading

Jay Harris & Steve McCabe, independent consultant

Objective:

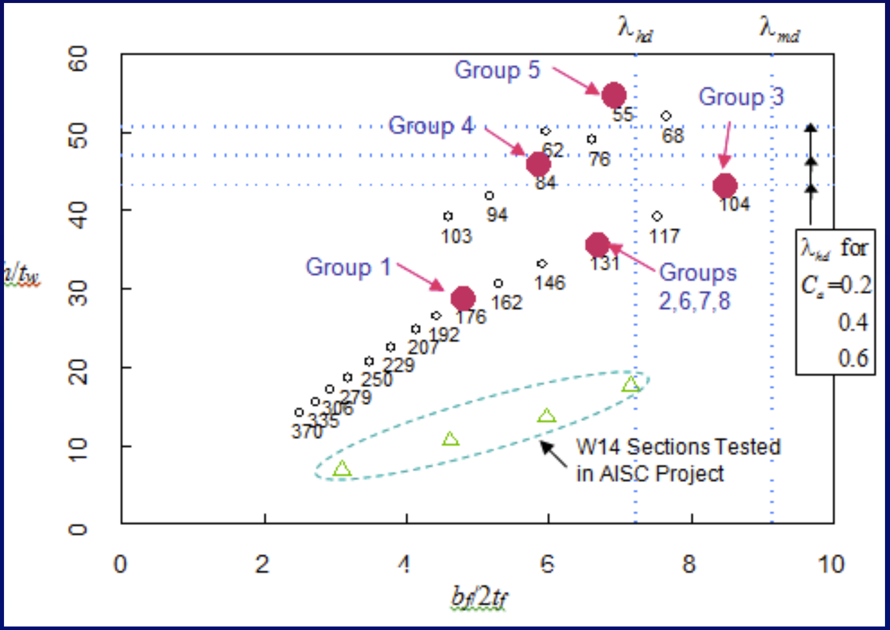
Provide important new experimental data and validated structural behavior models for refining key seismic design provisions in U.S. model building codes and standards used for designing steel wide-flange beam-columns

Research plan:

- Investigate twenty-five (25) deep, steel beam-column members that are stability-sensitive at large deformations
- Supplement full-scale experiments with finite element studies
- Develop improved AISC design provisions
- All data archived in the NEES Data Repository

# Stability of Steel Wide-flange Beam-Columns in Seismic Loading

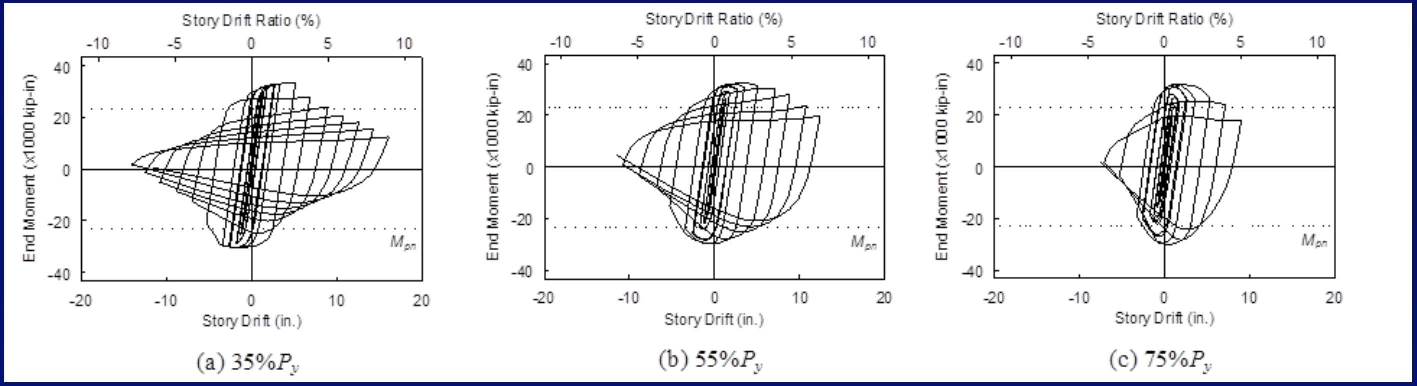
- Testing work at UCSD – 25 tests with specific sections, loadings and drift levels - completed



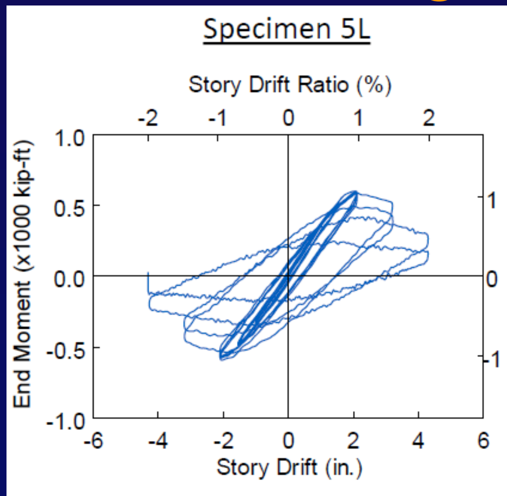

| Group No. | Specimen Designation | Shape | Max. Story Drift Imposed | Column Axial Load | |
|---|---|---|---|---|---|
| | | | | $C_a$ | *P* (kips) |
| 1 | 1L | W24×176 | 7% | 0.2 | 465 |
| | 1M | | 4% | 0.4 | 931 |
| | 1H | | 2% | 0.6 | 1396 |
| 2 | 2Z | W24×131 | 7% | 0.0 | 0 |
| | 2L | | 4% | 0.2 | 347 |
| | 2L-P | | 4% | 0.2 | 347 |
| | 2M | | 3% | 0.4 | 693 |
| | 2M-R | | 3% | 0.4 | 693 |
| | 2H | | 1.5% | 0.6 | 1040 |
| | 2H-R | | 1.5% | 0.6 | 1040 |
| 3 | 3L | W24×104 | 4% | 0.2 | 276 |
| | 3M | | 1.5% | 0.4 | 551 |
| | 3H | | 1% | 0.6 | 826 |
| 4 | 4L | W24×84 | 1.5% | 0.2 | 222 |
| | 4L-R | | 3% | 0.2 | 222 |
| | 4M | | 2% | 0.4 | 445 |
| 5 | 5L | W24×55 | 2% | 0.2 | 146 |
| | 5L-M | | 1% | 0.3 | 219 |
| | 5M | | 0.75% | 0.4 | 292 |
| 6 | 6L | W24×131 | 7% | 0.2 | 347 |
| | 6H | | 4% | 0.6 | 1040 |
| | 6L-P | | 7%/10% | 0.6 | 1040 |
| 7 | 7M-R | | 3% | 0.4 | 693 |
| | 7M | | 3% | 0.4 | 693 |
| 8 | 8M | | -2%/+6% | 0.4 | 693 |

# Stability of Steel Wide-flange Beam-Columns in Seismic Loading

- Test results illustrated a gap in fundamental knowledge about behavior of deep wide-flange steel beam-columns under cyclic inelastic demands.
- Interaction between web and flange local buckling was noticeable; however, current code provisions treat the two separately.
- Global buckling (flexural and torsional) was observed in a class of columns - it is not well understood what triggered this global buckling. Additional tests will investigate the root cause of global buckling failure modes in these columns.



# Stability of Steel Wide-flange Beam-Columns in Seismic Loading




Specimen 5L
(at 2% SDR)

Specimen 5LM
(at 1% SDR)

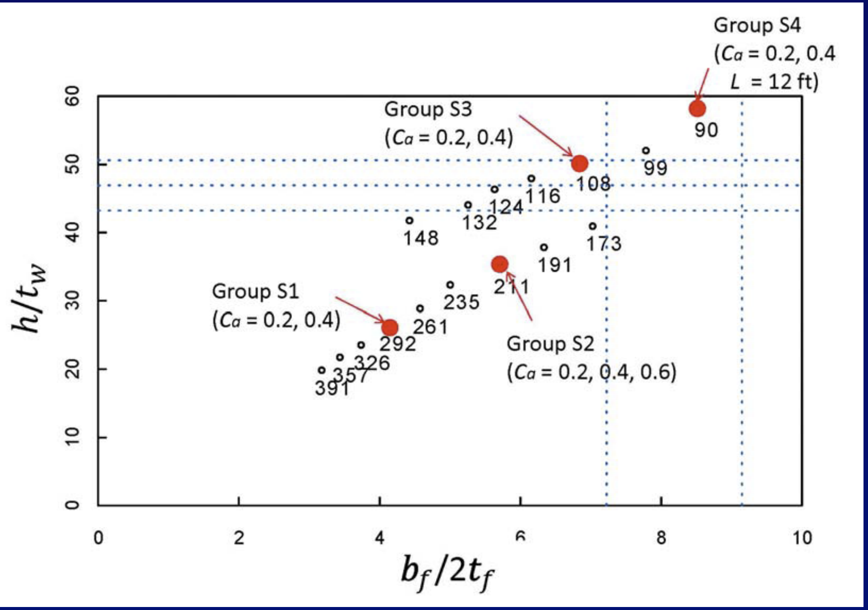
Specimen 5M
(at 0.75% SDR)

# Stability of Steel Wide-flange Beam-Columns in Seismic Loading

- Additional testing work at UCSD – to be awarded for FY2015
  - ~20 new specimens that have similar geometric attributes to the first set of specimens
  - ~6 additional specimens will repeat tests done in either series. These specimens will evaluate repeatability of observed phenomenon and provide insight into uncertainty and error in test results.

**Table 1 Supplemental Test Matrix**

| Group No. | Specimen Designation | Shape | $L$ (ft) | $C_a$ |
|---|---|---|---|---|
| S1 | S1L<br>S1M | W30×292 | 18 | 0.2<br>0.4 |
| S2 | S2L<br>S2L-P<br>S2M<br>S2H | W30×211 | 18 | 0.2<br>0.2<br>0.4<br>0.6 |
| S3 | S3L<br>S3L′<br>S3M<br>S3M′ | W30×108 | 18<br>12<br>18<br>12 | 0.2<br>0.2<br>0.4<br>0.4 |
| S4 | S4L<br>S4M | W30×90 | 12 | 0.2<br>0.4 |
| S5 | S5L<br>S5M | W24×55 | 12 | 0.2<br>0.4 |
| S6 | S6L<br>S6M | W18×71 | 18 | 0.2<br>0.4 |



# Seismic Response of Slender Reinforced Concrete Structural Walls

## Objective

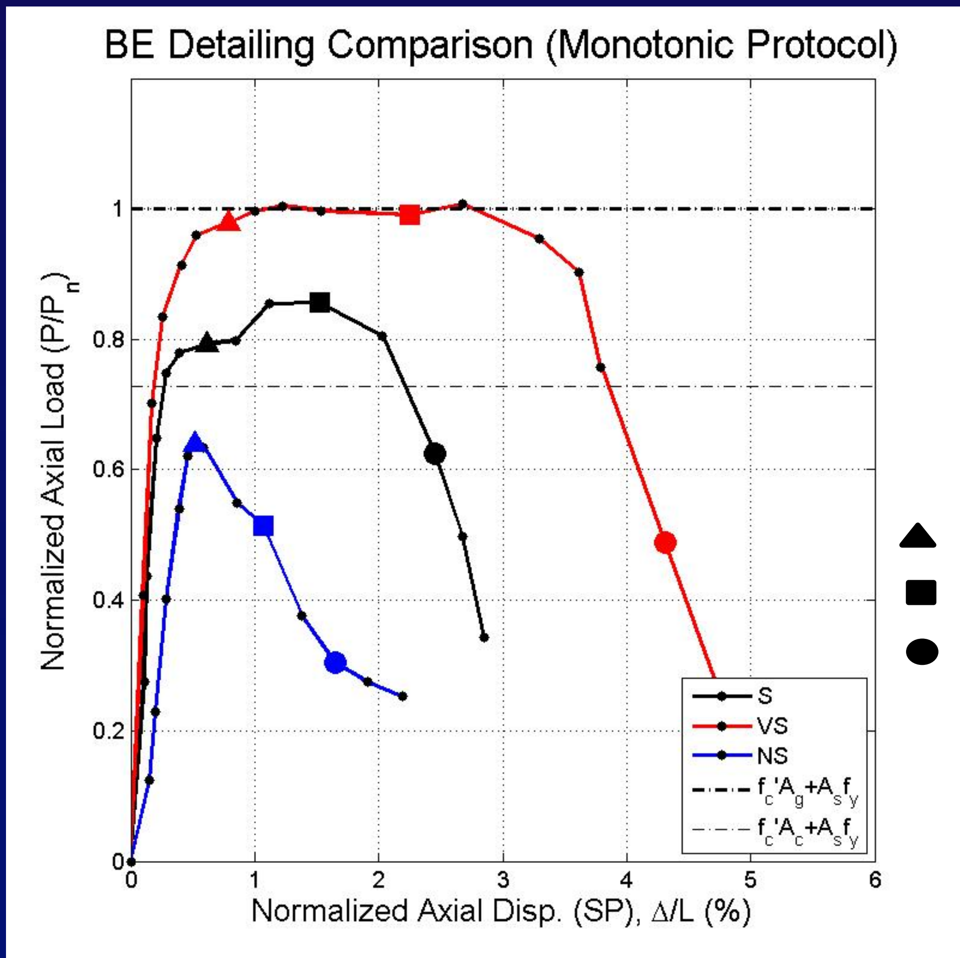
Validated slender wall design provisions to improve performance under strong shaking

- Testing performed at Corps of Engineers Construction Engineering Research Laboratory in Champaign
- Oversight by ATC under Task Order 30
- Heavy NIST involvement in technical issues and management
- All data archived in the NEES Data Repository

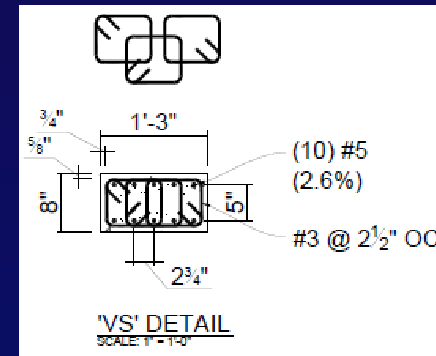
# Research Objectives and Goals

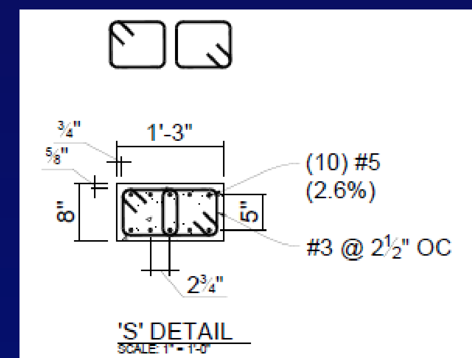
- Wall and boundary element prism tests to assess parameter sensitivity
  - slenderness
  - tension excursions
  - axial stress
  - confinement
- Status:
  - 20 boundary element prism tests completed and being analyzed
  - 4 wall specimens await testing

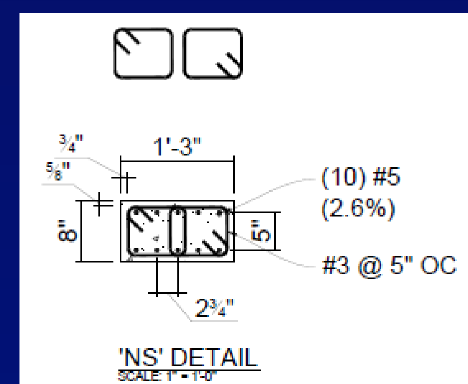
# Boundary Element Prism Results – Detailing




▲ Spalling
■ Crushing
● Bar Buckling




Results shown are preliminary

# Task Order 38 (ATC-114) – Analysis, Modeling and Simulation for Performance-Based Seismic Engineering – BigFoot

Goal: To critically evaluate the current evaluation and analysis approaches for Performance Based Seismic Engineering.

- Identify improved methods and acceptance criteria including backbone curves and other specific features
- Develop guidelines and best practices
- ASCE 7 and 41 standards used as a starting point for discussion.
- *Critical project* as Performance Based Design is being increasingly employed for new buildings and in evaluating existing buildings.

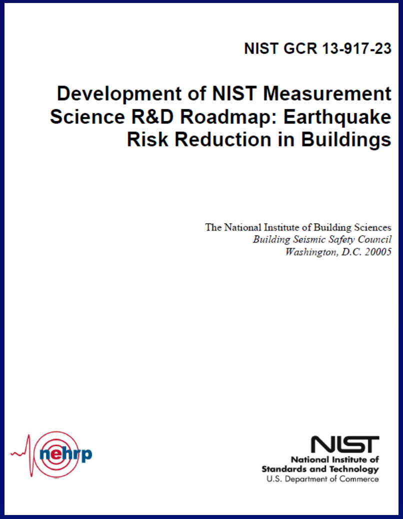
# Task Order 39 (ATC-120)

## SEISMIC ANALYSIS AND DESIGN OF NONSTRUCTURAL COMPONENTS AND SYSTEMS

Goal: To improve technical aspects of nonstructural system design in the areas that will have the largest impact for public safety and economic welfare.

Major achievements since 10/2014:

- Project team formed
- Kick-off video conference
- Draft Project Work Plan circulated for review by project team


NIST GCR 13-917-23

Development of NIST Measurement Science R&D Roadmap: Earthquake Risk Reduction in Buildings

The National Institute of Building Sciences
*Building Seismic Safety Council*
*Washington, D.C. 20005*

nehrp

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

7 of 25 "highest" priority items are related to nonstructural; including the $1^{st}$ & $2^{nd}$ ranked topics

# NIST/NEHRP – How are we doing with outreach?

National Institute of Standards and Technology: *February 2015 Media Scan and NEHRP.gov Google Analytics 2013-2015 Synopsis*

| | Page | Pageviews | % Pageviews |
|---|---|---|---|
| 2. | /library/techbriefs.htm | | |
| | Jan 1, 2014 - Dec 31, 2014 | 6,072 | 11.58% |
| | Jan 1, 2013 - Dec 31, 2013 | 5,766 | 10.49% |
| | **% Change** | **5.31%** | **10.38%** |
| 3. | /library/guidance_new.htm | | |
| | Jan 1, 2014 - Dec 31, 2014 | 4,719 | 9.00% |
| | Jan 1, 2013 - Dec 31, 2013 | 3,824 | 6.96% |
| | **% Change** | **23.40%** | **29.35%** |

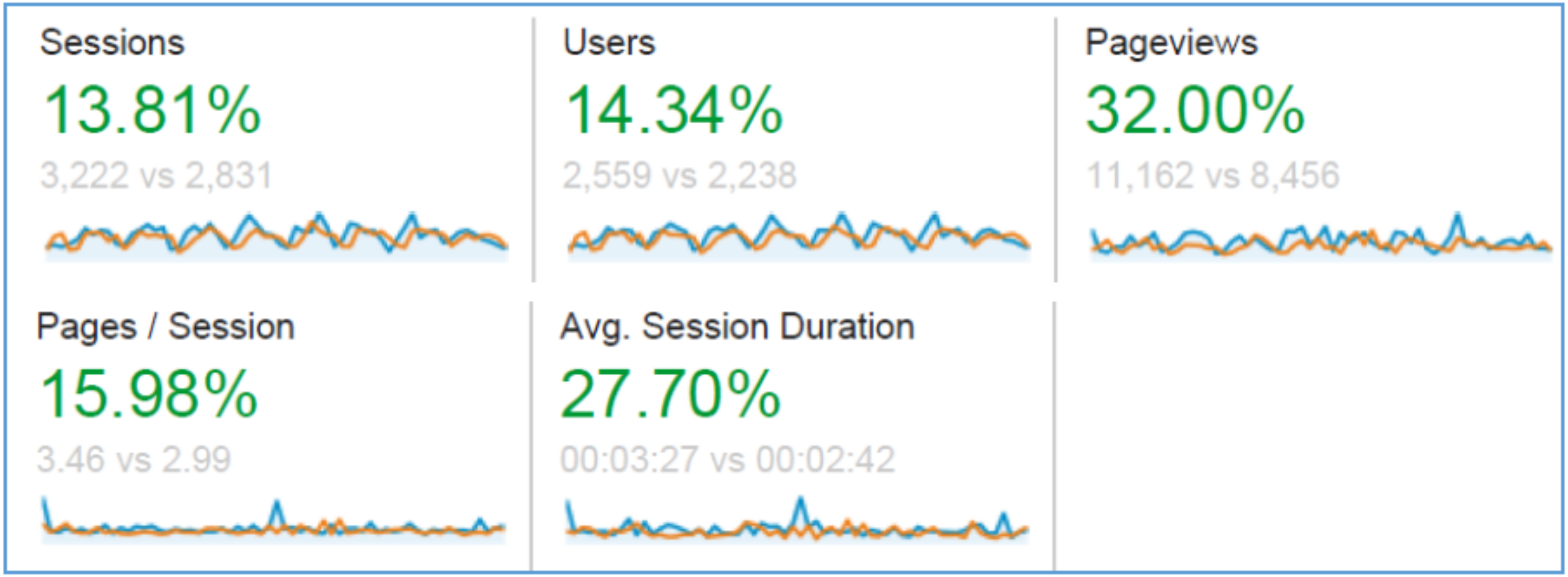
*Graphic 2.3: 2014 vs. 2013 Selected Top Viewed Pages*

Here is additional information about the top ten most viewed pages in 2014.

*Table 2.1: 2014 Top 10 Most Viewed Pages*

| | Page | Page Title | Pageviews | % of Total Pageviews | Avg Time Spent on Page |
|---|---|---|---|---|---|
| **1.** | /library/guidance.htm | NEHRP - Design & Construction | 6,950 | 13.25% | 00:00:22 |
| **2.** | /library/techbriefs.htm | NEHRP - Technical Briefs | 6,072 | 11.58% | 00:02:35 |
| **3.** | /library/guidance_new.htm | NEHRP - New Buildings | 4,719 | 9.00% | 00:03:34 |
| **4.** | /library/index.htm | NEHRP - Library | 3,777 | 7.20% | 00:01:09 |
| **5.** | /news/index.htm | NEHRP - News | 2,760 | 5.26% | 00:01:02 |
| **6.** | /library/guidance_steel.htm | NEHRP - Moment Resisting Frame Buildings | 1,873 | 3.57% | 00:01:31 |
| **7.** | /library/guidance_pbsd.htm | NEHRP - Performance-Based Design | 1,753 | 3.34% | 00:02:17 |
| **8.** | /library/guidance_existing.htm | NEHRP - Existing Buildings | 1,609 | 3.07% | 00:01:50 |
| **9.** | /about/reports.htm | NEHRP - Annual Reports & Plans | 1,427 | 2.72% | 00:01:03 |
| **10.** | /library/clearinghouse.htm | NEHRP Clearinghouse | 1,277 | 2.44% | 00:01:03 |
| | | | **Total Views on Top 10 Pages: 32,217** | **% of Total Pageviews: 61.43%** | **Avg Time on Top 10 Pages: 1:51** |

# In 2015, Business is Booming




*Graphic 3.1: Jan-Mar 2015 vs. Jan-Mar 2014 NEHRP.gov Session Overview*

# In Summary

- Significant **results**
- Important new knowledge, tools and code provisions
- Outreach through technical committees and publications
- Important accomplishments and impact

# Questions?